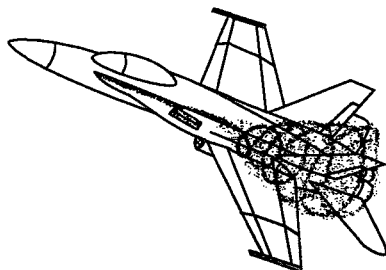


Correlation of F/A-18 Tail Buffet Results



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NOTES

Abstract

Tail Buffet measurements from the second full-scale F/A-18 wind tunnel test are presented and compared with small-scale wind tunnel measurements, recent flight test measurements, and CFD computations performed a few years ago. Non-dimensional power spectra for unsteady pressures at the 60%-span, 45%-chord location on the vertical tail are presented from several small-scale wind tunnel tests, from the full-scale wind tunnel tests, and from flight tests. Data are presented for the F/A-18 with and without the LEX fence. The data show that the dominant frequency of the unsteady fin pressure scales with velocity and inversely with model size. The CFD predictions are shown to give a reasonably close prediction of the principal buffeting frequency for the LEX fence off configuration, but they failed to predict the correct trends for the change in frequency and power for the LEX fence on configuration. The comparisons to CFD results indicate that future numerical simulations of tail buffet will require significantly increased grid densities and longer simulated time records. The experimental comparisons indicate that small-scale wind-tunnel test results can be used to adequately predict the frequency and power of buffeting pressures in flight. Furthermore, the small-scale wind-tunnel tests seem to reliably predict trends due to configuration changes.

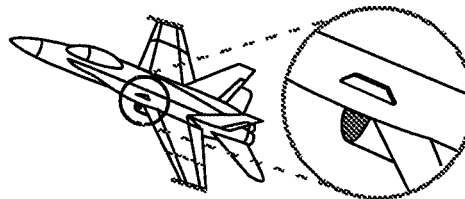
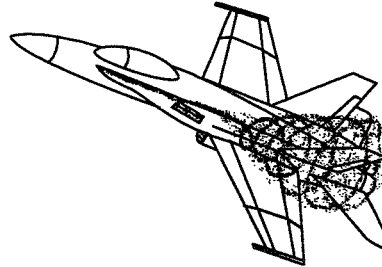
Outline

- **Background**
- **Objectives & Approach**
- **Tail Buffet Characteristics**
- **Flight, Wind-Tunnel, & CFD Comparisons**
- **Summary of Results**

NOTES

Background

- **Tail Buffet**
 - Due to Vortex Burst
 - LEX Vortices
 - Twin-Tail Aircraft
 - Significant Problem for Early F/A-18's
- **LEX Fence**
 - Retrofit to the F/A-18
 - Significant Increase in Fatigue Life



NOTES

The most prominent source of tail buffeting is vortex burst. This is typically a problem for aircraft that utilize leading-edge extensions (LEXs), since LEX vortices tend to be much stronger than forebody vortices and wing leading-edge vortices. Tail buffet is most serious for twin tailed aircraft, because the vertical tails are closer to the wake of the burst vortex.

Tail buffet was a major concern for the first production F/A-18 fighter aircraft. Buffeting on these aircraft drastically reduced the fatigue life of the vertical tails. Two retrofits were used to alleviate the problem. First, the fin root support for the vertical tails was reinforced. Second, a vertical plate, known as the LEX fence, was installed on the LEX at the LEX/wing junction. The LEX fence was shown to significantly reduce buffeting of the vertical tails and thereby increased the fatigue life of the vertical tails.

Given this history, the F/A-18 is an ideal test bed for tail buffet research. Intense buffeting conditions can be studied by removing the LEX fence and the characteristics of alleviated buffeting can be studied with the LEX fence installed.

Objectives & Approach

- **Objectives**

- Develop Guidelines for Applying Small-Scale Test Results to Flight
- Provide Data for CFD Validation

- **Approach**

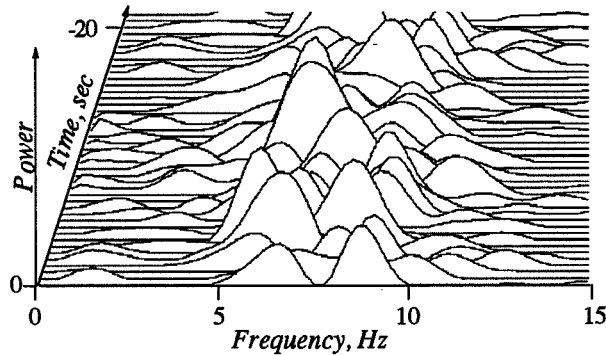
- Compare Spectral Characteristics of Pressures at a Common Location
 - » Flight Tests
 - » Full-Scale & Small-Scale Wind Tunnel Tests
 - » Early CFD Predictions
- Types of Comparisons
 - » Full Power Spectra for Differential Pressure
 - » Variation of Spectral Characteristics with Angle-of-Attack for Inboard, Outboard, & Differential Pressures
 - » LEX Fence Effects

NOTES

One of the main objectives of full-scale wind tunnel and flight test tail buffet research on the F/A-18 was to validate scaling laws for use in estimating flight tail buffet loads from small-scale wind tunnel test results. A closely related objective was to acquire data for the validation of numerical simulations of tail buffet. As a first step towards achieving the first objective, comparisons were made of the non-dimensional power spectra from several different small-scale wind tunnel tests, from full-scale wind tunnel tests, and from flight tests. In this study, comparisons were made between the power-spectra of pressures measured at a location on vertical tail that was common to all tests. This presentation includes comparisons of full power spectra for differential pressure for a few angles-of-attack; comparisons of the variation of spectral characteristics with angle-of-attack for differential, inboard, and outboard surface pressures; and comparisons of the effect that the LEX fence has on the power spectra of the surface pressures. High fidelity, numerical simulations of F/A-18 tail buffet were not available for comparison. However, some results from the very first numerical simulations of F/A-18 tail buffet are included in a few of the comparison plots.

Tail Buffet Pressure Characteristics

Typical Time / Frequency Plot



NOTES

The above figure shows a series of 1/2 second power spectral distributions (PSDs) for a typical tail buffet pressure signal. As can be seen, the variation of the PSDs with time is quite significant. Signals like this are said to have "noise-like" properties and significant time-averaging is required to reduce error in the PSD estimates. It is also desirable to have lengthy time records, since short time records are more likely to contain disproportionate periods of low or high buffeting.

Non-Dimensional Parameters

Dimensional Parameters

frequency, f (Hz)

unsteady pressure, p' (psi)

pressure power, p'' (psi²/Hz)

Non-Dimensional Parameters

Non-Dimensional Frequency, $K = \frac{f \bar{c}}{U_{\infty}}$

Unsteady Pressure Coefficient, $Cp' = \frac{p'}{\frac{1}{2} \rho U_{\infty}^2}$

Pressure Power Coefficient, $Cp'' = \frac{4p''}{\bar{c} \rho^2 U_{\infty}^3}$

NOTES

The derivations of non-dimensional parameters for frequency and buffet pressure PSDs are given in Reference 1. The definitions for the non-dimensional frequency, K , and the PSD pressure coefficient, Cp'' , use the mean aerodynamic chord for the characteristic length scale and the free stream velocity, U_{∞} , was chosen as the characteristic velocity.

Test Article Comparisons

Test Article	Mach Number	Reynolds Number	Organization
Flight Test	0.3	12×10^6	NASA DFRC
Full-Scale	0.15	12×10^6	NASA ARC
16%-Scale	0.08	1.0×10^6	NASA LaRC
12%-Scale	0.07	0.7×10^6	McDonnell Douglas
6%-Scale	0.6	3.4×10^6	IAR (Canada)
CFD	0.24	9.4×10^6	NASA ARC

•Data Presented for Pressure at the 45%-Chord / 60%-Span Location

•CFD Results for the 50%-Chord / 50%-Span Location

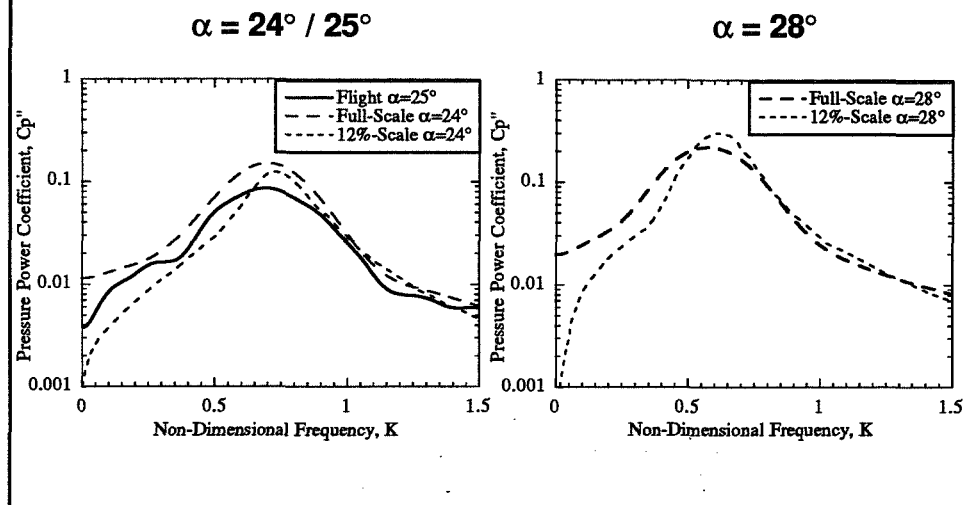
NOTES

The flight test data and the full-scale and small-scale wind-tunnel data presented in this paper are for pressures measured at the 45%-chord and 60%-span location. The CFD data are presented for pressures at the 50%-chord, 50%-span location. The flight test data and the full-scale wind-tunnel data are from the most recent tests at NASA DFRC and NASA ARC. Most of this data has not been published. The small-scale wind-tunnel data^{1,3,5} and the CFD^{7,8} results are from previously published reports. Where available, data for the LEX fence on and off configurations are presented.

As can be seen in the table, data acquired over a wide range of Mach numbers and Reynolds numbers are compared. Steady-state characteristics of the F/A-18 LEX vortex are not very sensitive to changes in Reynolds number, but previous tests have shown that the pressure signature of the LEX vortex on the LEX is very sensitive to Mach number. Flight test data for Mach 0.6 has been acquired, but was not available for comparison in this paper. Some conclusions about Mach number sensitivity might be made from the data presented here, but it would be best to wait until the flight test data is available.

It should be noted that the CFD predictions are the first attempts to model the extremely difficult problem of unsteady vortex burst on a complex aircraft. Only 0.9 million grid points were used for the entire flowfield and the time accurate calculations were carried out for simulated time period of only 0.6 sec. Given the low grid density and the extremely short time history, results from the numerical simulation can be expected to have a high degree of uncertainty. The important thing to look for in the CFD results is whether or not basic trends found in the experimental results are predicted.

Power Spectra Comparisons Scale Effects, LEX Fence Off Differential Pressure



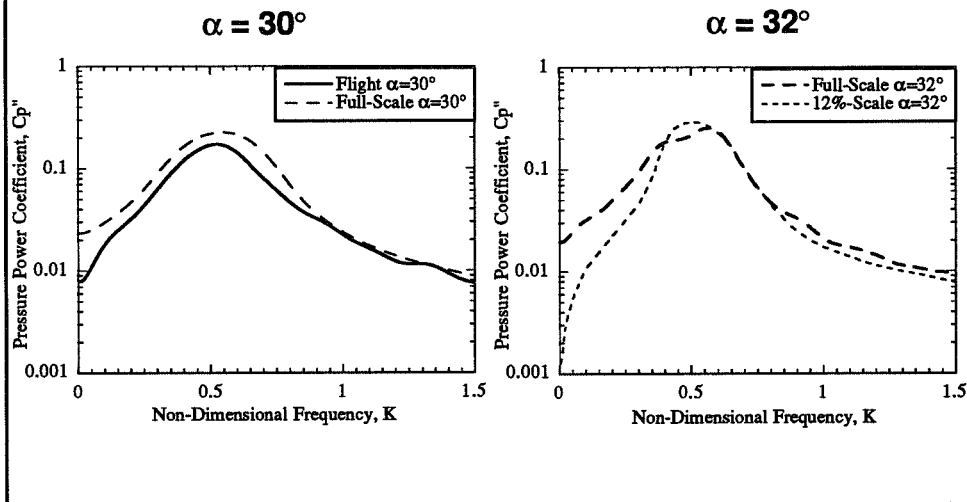
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The power spectra of the differential pressures from flight test and the full-scale and 12%-scale wind-tunnel tests for several angles-of-attack are presented in this figure and the next. The frequency at which the peak power occurs is similar for all the comparisons. Additionally, the power levels for frequencies greater than the peak power frequency are in very good agreement. However, at the lower frequencies, the power levels for the full-scale wind-tunnel test are greater than the power levels for the flight test and, in turn, the flight test power levels are greater than the 12%-scale wind-tunnel power levels. The magnitude of the peaks for each test are close, but there is some scatter.

Power Spectra Comparisons

Scale Effects, LEX Fence Off (Continued)

Differential Pressure



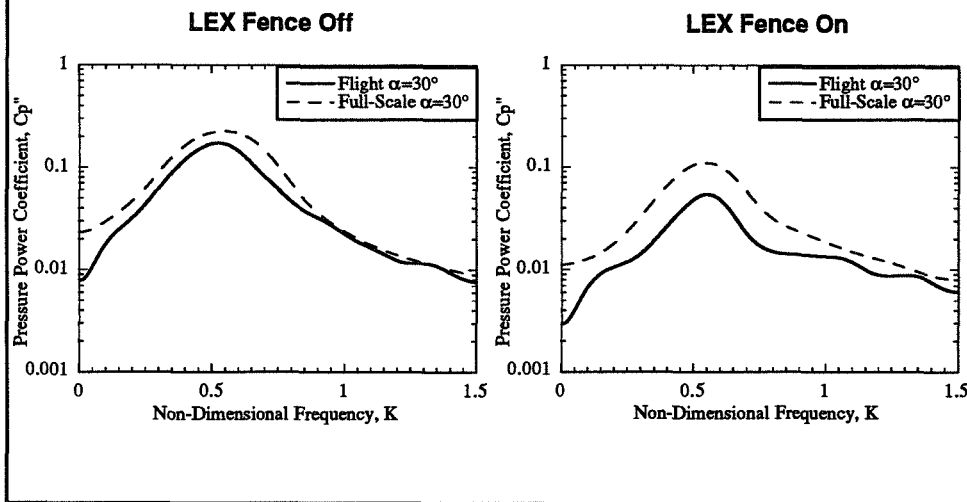
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Power Spectra Comparisons

LEX Fence Effects

Differential Pressure

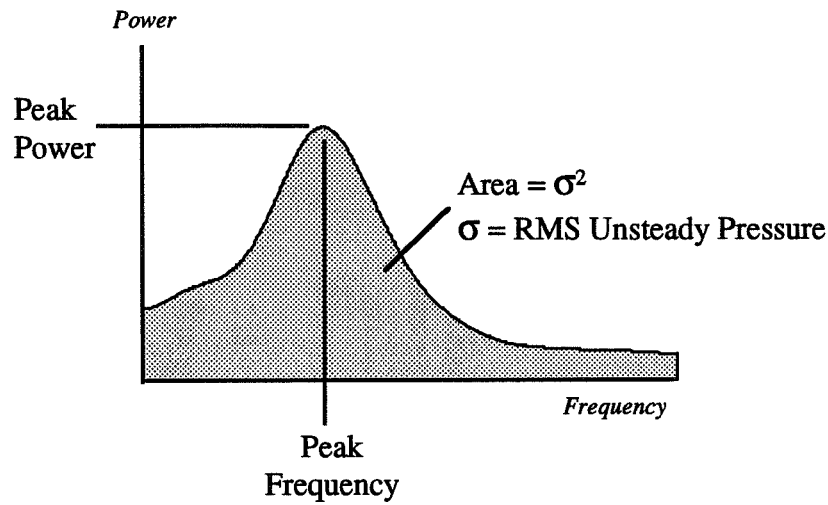
$\alpha = 30^\circ$



NOTES

The power spectra for the differential pressure at 30° angle-of-attack are shown here for both the flight test and the full-scale wind-tunnel test. Both the LEX fence off and the LEX fence on configurations are shown. Although, the power levels are greater for the full-scale wind tunnel data, the peak power frequencies agree very well. For both the full-scale and flight data, the LEX fence is shown to decrease power levels. In this particular comparison, the LEX fence seems to be slightly more effective in the flight test than it is for the full-scale wind-tunnel test.

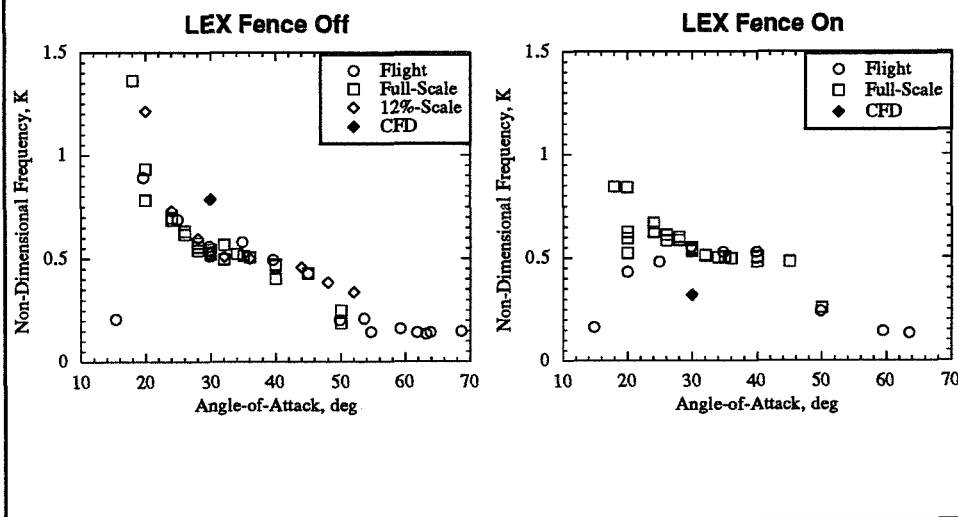
Power Spectra Metrics



NOTES

In order to simplify the comparison of several power spectra at once, three descriptive metrics were chosen. These are the frequency at which the peak in the power spectrum occurs, the value of the peak in the power spectrum, and the square root of the area under the power spectrum curve. Since the area under the power spectrum curve is equal to the variance of the pressure signal, the square root of the area is equal to the root-mean-square (RMS) of the unsteady pressure. The unsteady pressure is defined as the pressure signal with the mean pressure removed.

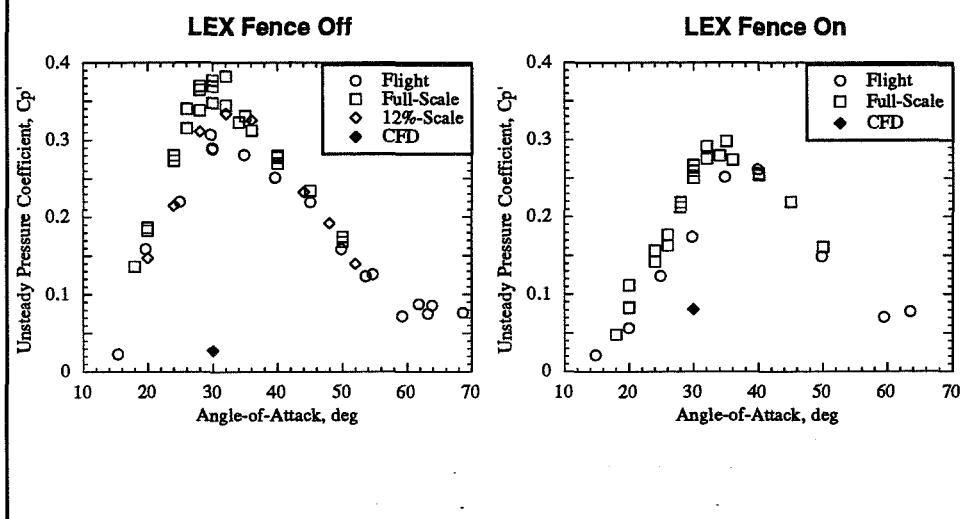
Peak Power Frequency vs. Angle-of-Attack LEX Fence Effect Differential Pressure



NOTES

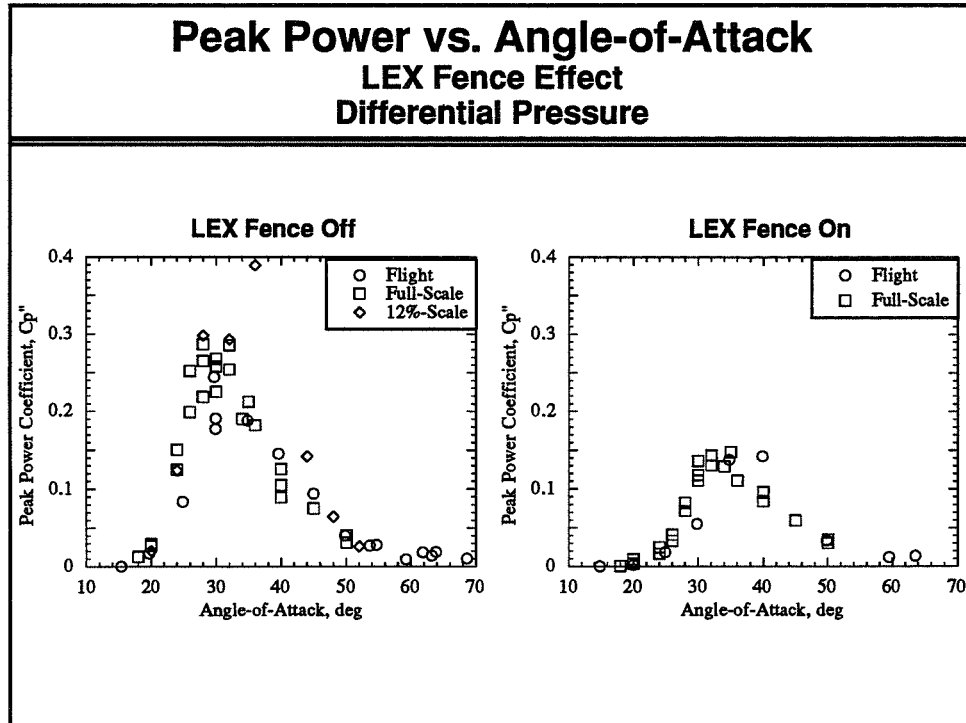
The non-dimensional peak power frequency for flight, full-scale, and 12%-scale test results compare very well over the entire angle-of-attack range. The only exception is for angles-of-attack less than 25° where there is significant scatter in the data. The power spectra at these low angles-of-attack have extremely low power levels and often have poorly defined peaks, which significantly increases the uncertainty the peak power frequencies. For angles-of-attack above 25°, the experimental data indicates that the LEX fence has very little effect on the peak power frequency. The CFD solution over predicts the peak power frequency for the LEX fence off configuration and, unlike the experimental data, the CFD solution shows a significant reduction in the peak power frequency for the LEX fence on configuration.

RMS Unsteady Pressure vs. Angle-of-Attack LEX Fence Effect Differential Pressure



NOTES

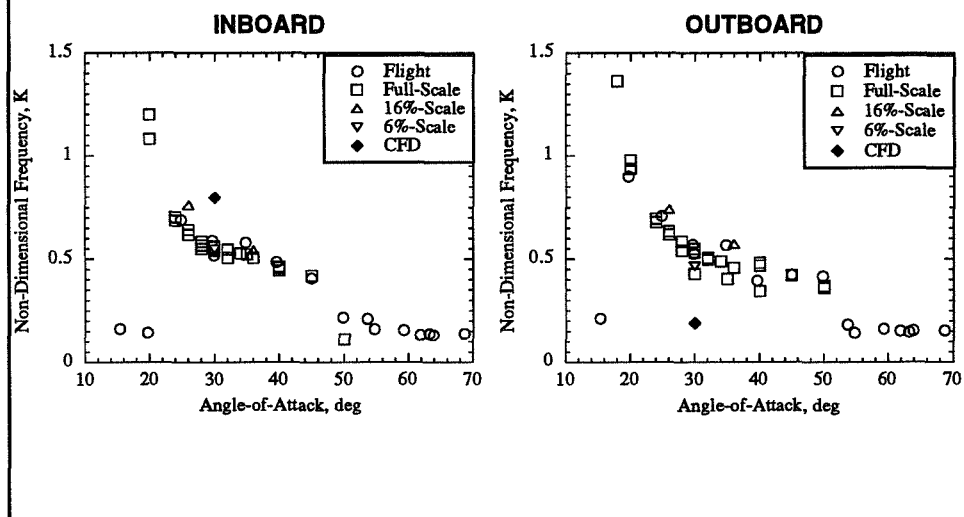
A fair amount of scatter is seen in the experimental data, especially near 30° angle-of-attack, where the largest unsteady pressures occur. Both the full-scale and 12%-scale unsteady pressures are slightly, but consistently, higher than the flight test unsteady pressures. Agreement between all the experimental data sets for angles-of-attack greater than 40° is extremely good. The experimental data indicates that the LEX fence reduces the unsteady pressure levels for angles-of-attack less than 50°. The CFD solutions show significantly lower unsteady pressure levels than shown in the experiments. Additionally, the CFD solutions predict an increase the unsteady pressure level for the LEX fence on configuration, which is contrary to the experimental results.



NOTES

A considerable amount of scatter is seen in the experimental data near 30° angle-of-attack, where the largest unsteady pressures occur. Both the full-scale and 12%-scale peak powers are slightly, but consistently, higher than the flight test peak powers for angles-of-attack less than 40°. At an angle-of-attack of 36°, the 12%-scale data shows an extremely high peak power level for the LEX fence off configuration. This may be a randomly high point or it is possible that the “rigid” fin on the model may have been resonating at that condition. Overall, the experimental data show that the LEX fence significantly reduces the peak power levels for angles-of-attack less than 50°.

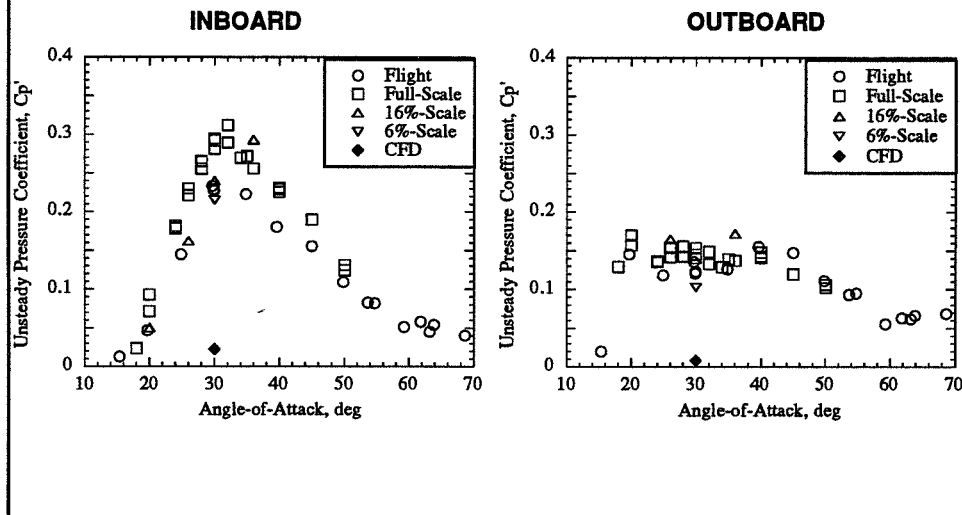
Peak Power Frequency vs. Angle-of-Attack Inboard & Outboard Pressure LEX Fence Off



NOTES

The peak power frequency for flight and for the full-scale, 16%-scale, and 6%-scale wind-tunnel models are presented for the inboard and outboard surface pressures. The experimental frequencies agree very well for the inboard surface pressures; however, the frequencies for the outboard surface pressure show more scatter. The higher scatter in the outboard frequencies is most likely due to lower power levels on the outboard surface. Overall, the peak power frequencies at each angle-of-attack are the same for both surfaces. The CFD solution predicts a significantly lower the peak power frequency on the outboard than on the inboard surface.

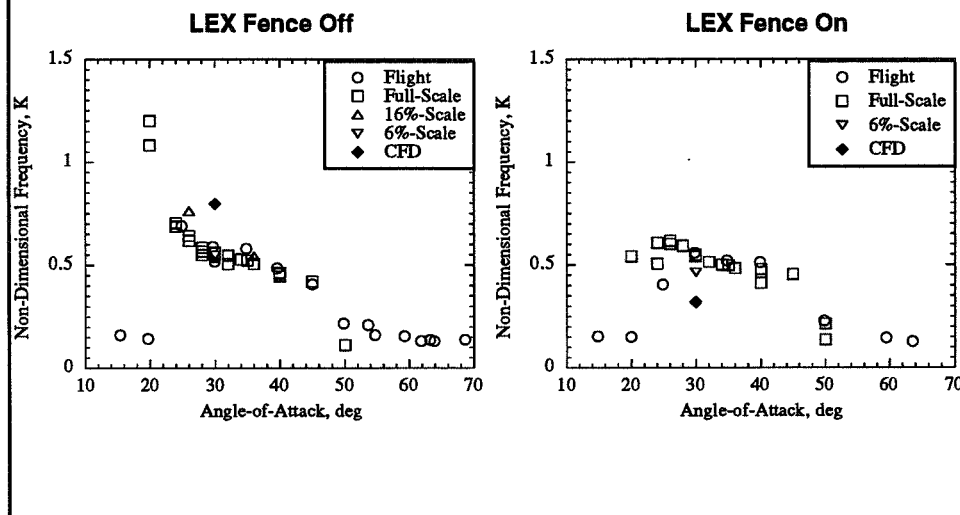
RMS Unsteady Pressure vs. Angle-of-Attack Inboard & Outboard Pressure LEX Fence Off



NOTES

The RMS unsteady pressure levels for flight and for the full-scale, 16%-scale, and 6%-scale wind-tunnel models are presented for both the inboard and outboard surfaces. As with the differential unsteady pressures, there is some scatter in the experimental data. For angles-of-attack from 25° to 50°, the data from the flight tests and the wind tunnel tests show significantly lower unsteady pressures on the outboard surface, as compared with the inboard surface. The CFD solution also shows a lower unsteady pressure level on the outboard surface as compared with the inboard surface.

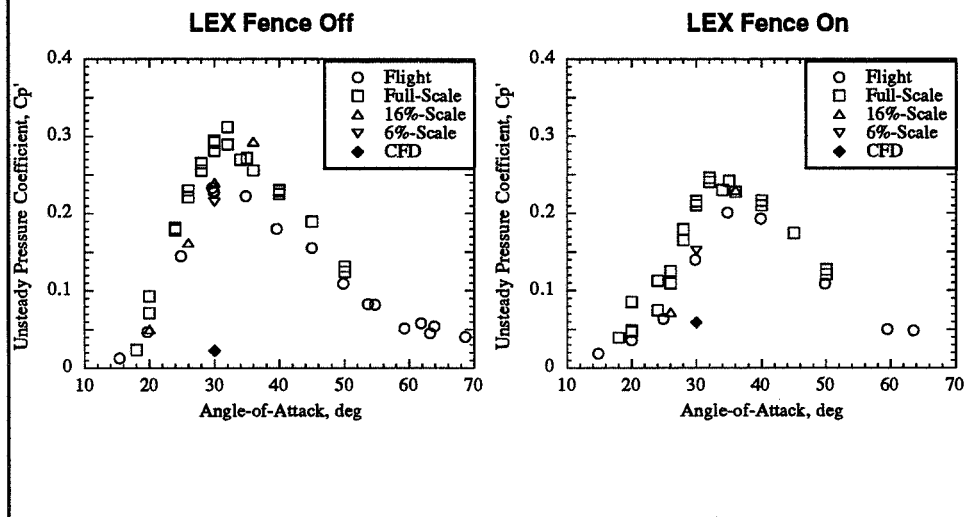
Peak Power Frequency vs. Angle-of-Attack LEX Fence Effect Inboard Pressure



NOTES

The LEX fence effect on the peak power frequency of the inboard surface is shown in the above figure. The peak power frequencies shown are nearly that same as the peak power frequencies for differential pressure. Note that the 16%-scale and 6%-scale wind-tunnel data show the same trends that are seen for the full-scale wind-tunnel and flight test data.

RMS Unsteady Pressure vs. Angle-of-Attack LEX Fence Effect Inboard Pressure



NOTES

The LEX fence effect on the RMS unsteady pressures on the inboard surface is shown in the above figure. The magnitude of the RMS unsteady pressures on the inboard surface shown above are slightly lower than the differential RMS unsteady pressures that were shown earlier. However, the reductions in RMS unsteady pressure levels due to the LEX fence are similar to those found for the differential pressure measurements. Note that the 16%-scale and 6%-scale wind-tunnel data show the same trends that are seen for the full-scale wind-tunnel and flight test data.

Summary of Results

- **Small-Scale, Full-Scale, & Flight Comparisons**
 - Very Good Agreement on Peak Power Frequency
 - Good Agreement on RMS Unsteady Pressure Levels
 - Fair to Good Agreement on Peak Power Levels
 - Relationships Between Inboard & Outboard Pressures are Consistent
 - LEX Fence Effects are Consistent
- **Computational Results**
 - Greater Grid Resolution Needed
 - Longer Time Records Needed
 - Experimental Database Could Prove Useful in Refining Modelling Techniques

NOTES

Overall there was very good agreement for the non-dimensional peak power frequencies for all the experimental test results. There was good agreement for the non-dimensional RMS unsteady pressure levels and fair to good agreement for the non-dimensional peak power levels. The relationship between the inboard and outboard pressure power spectra was consistent for all the experimental tests and the effect of the LEX fence was similar at all model scales and for flight. Based on these findings, small-scale tests should be quite adequate for estimating the magnitude and the spectral characteristics of unsteady buffet pressures in flight.

It is evident from the results presented that future numerical simulations should have greater grid resolution and they should simulate longer time periods. The large amount tail-buffet data now available for the F/A-18 should prove useful in refining and validating any future numerical simulations.

References

- 1 Zimmerman, N.H. and Ferman, M.A.: "Prediction of Tail Buffet Loads for Design Application," NADC-88043-60, July 1987.
- 2 Martin, C.A.; Glaister, M.K.; MacLaren, L.D.; Meyn, L.A.; and Ross, J.: "F/A-18 1/9th Scale Model Tail Buffet Measurements," Flight Mechanics Report 188, Aeronautical Research Laboratory, Melbourne Australia, June 1991.
- 3 Shah, G.H.: "Wind-Tunnel Investigation of Aerodynamic and Tail Buffet Characteristics of Leading-Edge Extension Modifications to the F/A-18," AIAA Paper 91-2889, Atmospheric Flight Mechanics Conference, August 1991.
- 4 Shah, G.H.; Grafton, S.B.; Guynn, M.D.; Brandon, J.M.; Dansberry, B.E.; and Patel, S.R.: "Effect of Vortex Flow Characteristics on Tail Buffet and High-Angle-of-Attack Aerodynamics of a Twin-Tail Fighter Configuration," High-Angle-of-Attack Technology Conference, October 1990.
- 5 Lee, B.H.K. and Brown, D.: "Wind-Tunnel Studies of F/A-18 Tail Buffet," Journal of Aircraft, Vol. 29, No. 1, 1992, pp. 146-152.
- 6 Lee, B.H.K. and Tang, F.C.: "Characteristics of the Surface Pressures on a F/A-18 Vertical Fin Due to Buffet," Journal of Aircraft, Vol. 31, No. 1, 1994, pp. 228-235.
- 7 Rizk, Y.M. and Gee, K.: "Numerical Prediction Of The Unsteady Flowfield Around The F-18 Aircraft At Large Incidence," AIAA Paper 91-0020, 29th Aerospace Sciences Meeting, January 1991.
- 8 Rizk, Y.M.; Guruswamy, G.P.; and Gee, K.: "Computational Study of F-18 Vortex Induced Tail Buffet," AIAA Paper 92-4699, 4th Symposium on Multidisciplinary Analysis and Optimization, September 1992.
- 9 Corsiglia, V.R.; Olson, L.E.; and Falarski, M.D.: "Aerodynamic Characteristics of the 40- by 80/80- by 120-Foot Wind Tunnel at NASA Ames Research Center," NASA TM 85946, April 1984.
- 10 Meyn, L.A.; Lanser, W.R.; and James, K.D.: "Full-Scale High Angle-of-Attack Tests of an F/A-18," AIAA Paper 92-2676, 10th Applied Aerodynamics Conference, June 1992.
- 11 Meyn, L.A. and James, K.D.: "Full-Scale Wind Tunnel Studies of F/A-18 Tail Buffet," AIAA Paper 93-3519, 11th Applied Aerodynamics Conference, August 1993.
- 12 Levraea, V.J.; Henderson, D.A.; Pacia, A.P.; Banford, M.P.: "Modal Survey of a Full-Scale F-18 Wind Tunnel Model," Wright Laboratory, WL-TM-92-350-FIBG, September 1992.
- 13 Marple, S.L. Jr., Digital Spectral Analysis with Applications, Prentice-Hall Inc., New York, 1987.
- 14 James, K.D. and Meyn, L.A.: "Dependence of Integrated Vertical-Tail Buffet Loads For F/A-18 on Sensor Density," SAE Paper 941140, SAE Aerospace Atlantic Conference, April 1994.